Performance of a Neutron Imaging Detector Based on the μPIC Micro-Pixel Gaseous Chamber

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Japan Atomic Energy Agency
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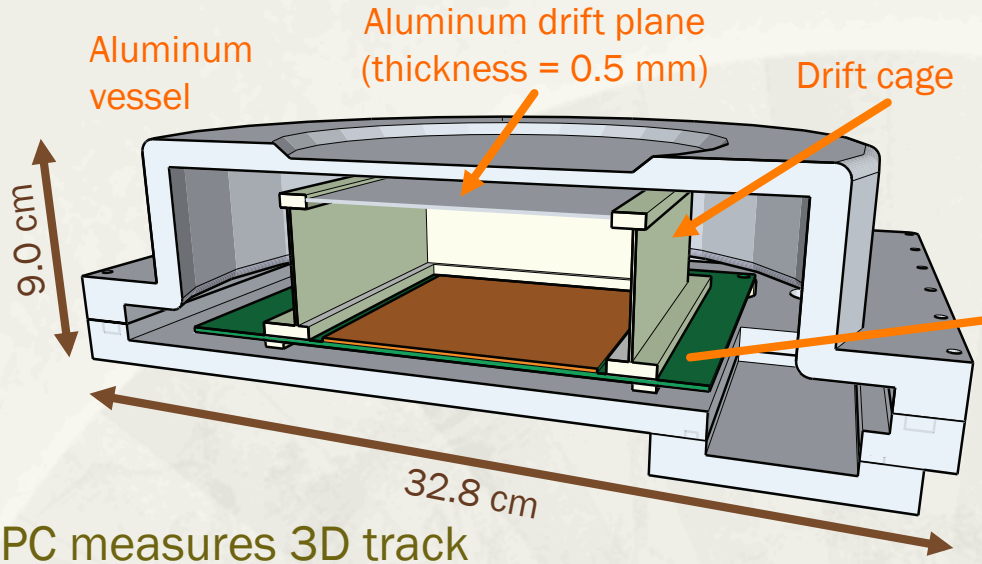
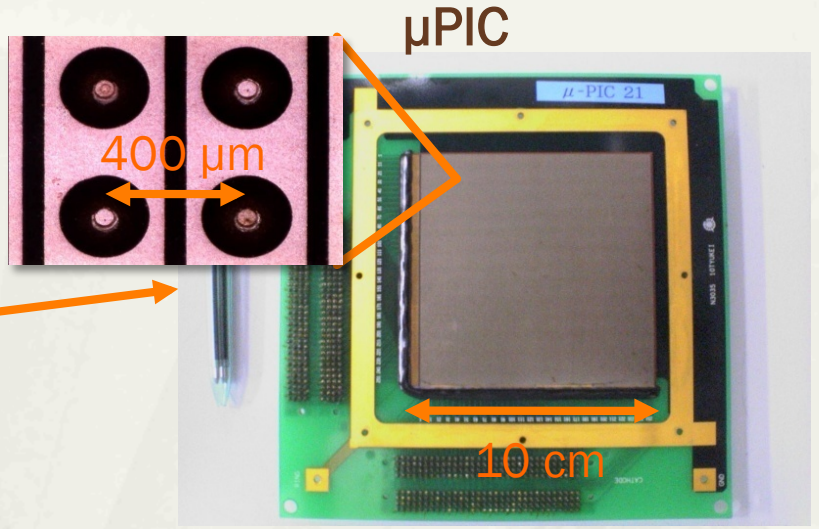
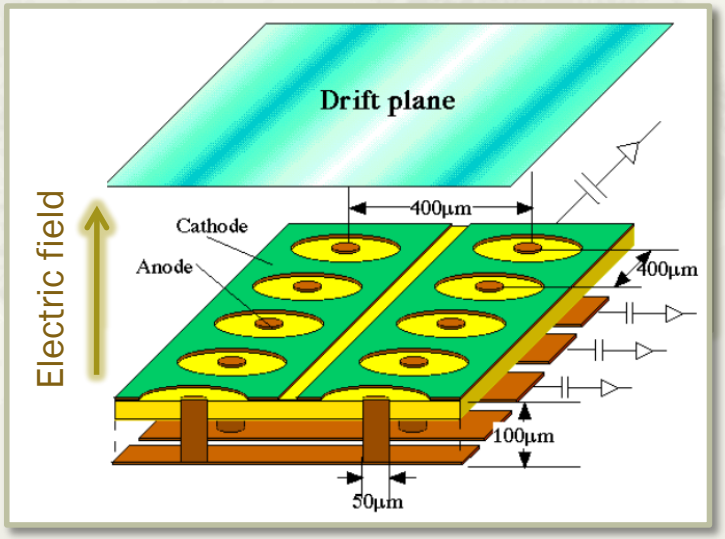
Neutron imaging detector prototype (μNID)



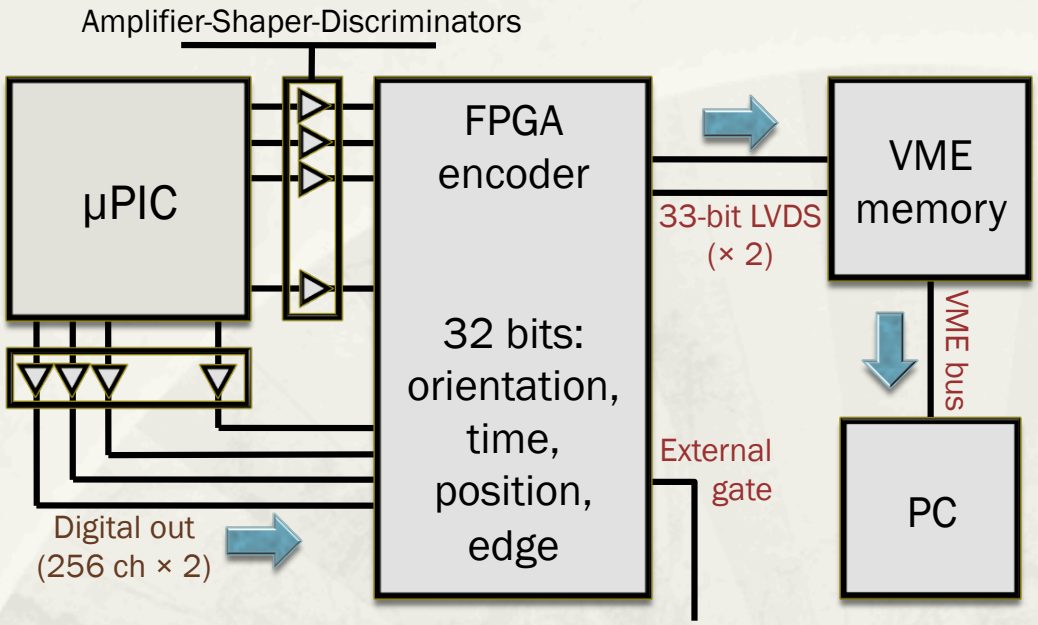


TPC measures 3D track of proton-triton pair.

- 10 × 10 cm^2 μPIC.
- Gas mixture: Ar-C_2H_6-^{3}He (up to 2 atm total pressure).
- Gas gain < 1000 for neutron imaging.
- Detection efficiency: up to ~30% for thermal neutrons.
- Position resolution: < 0.4 mm; time resolution: ~1 μs (for each neutron event).

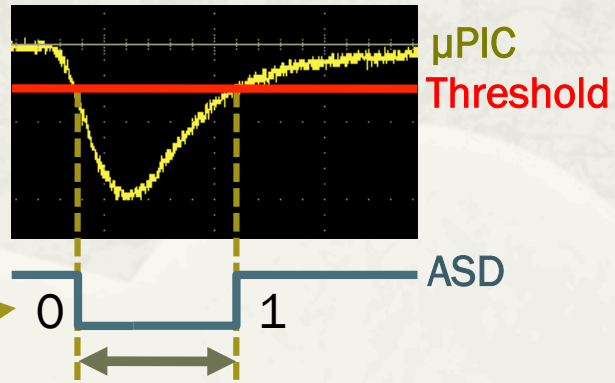


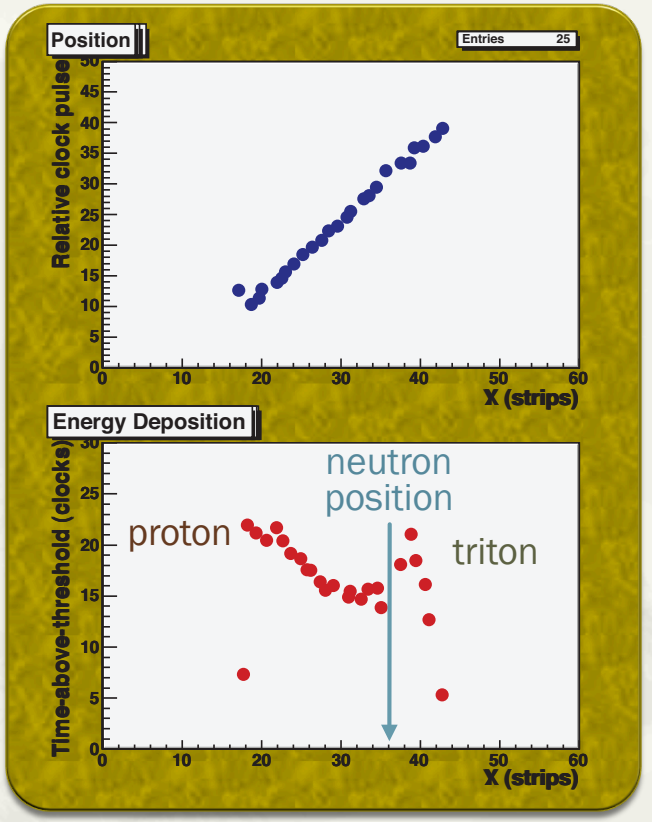
DAQ with X-ray mode 8



Data structure

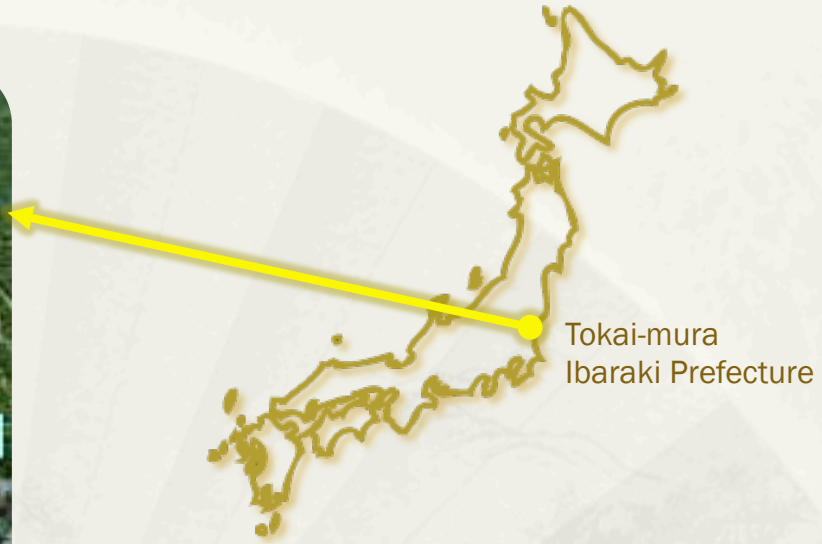
1 bit	orientation
20 bits	time
10 bits	strip no.
1 bit	edge

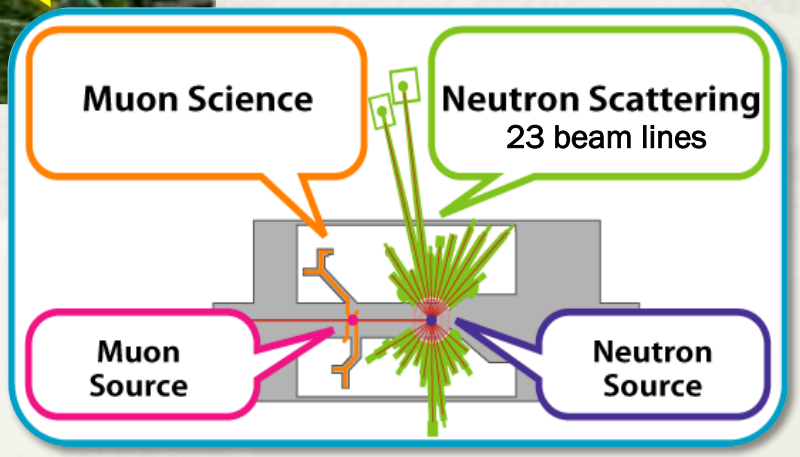




Simultaneous measurement of position and energy deposition at high rates.

Test experiments at J-PARC

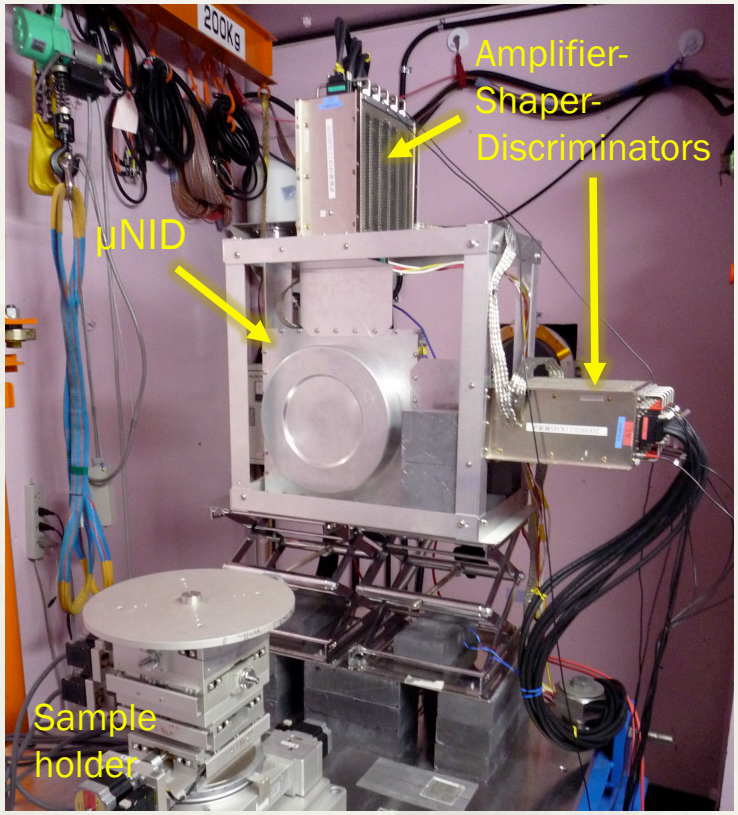




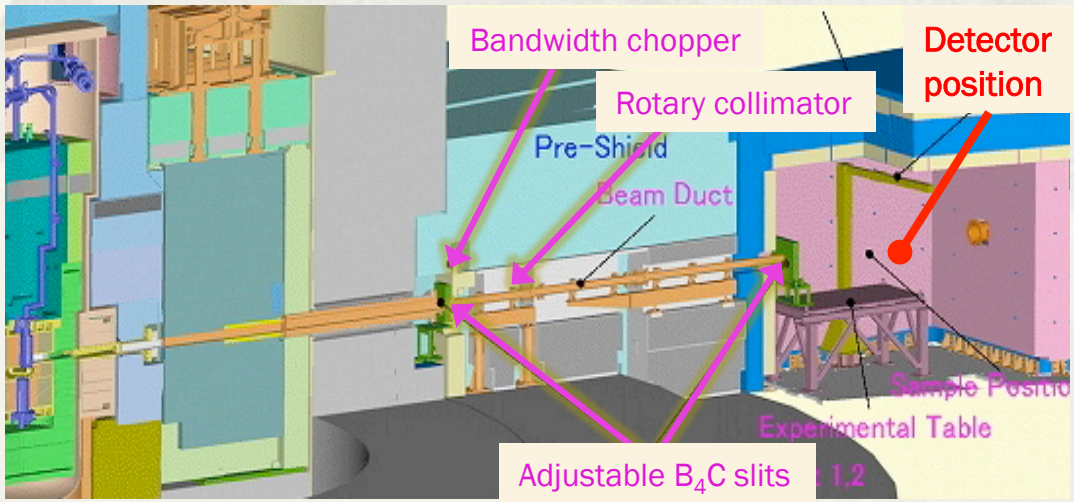
Japan Spallation Neutron Source (JSNS)

Test experiments at J-PARC

- Experiments in Nov. 2009 and June 2010.
- JSNS beam power ~120 kW.
- Ar(63%)-C_2H_6(7%)-^{3}He(30%) at 2 atm (detection efficiency ~28%).
- Same gas filling used for both experiments (separated by 8 months).



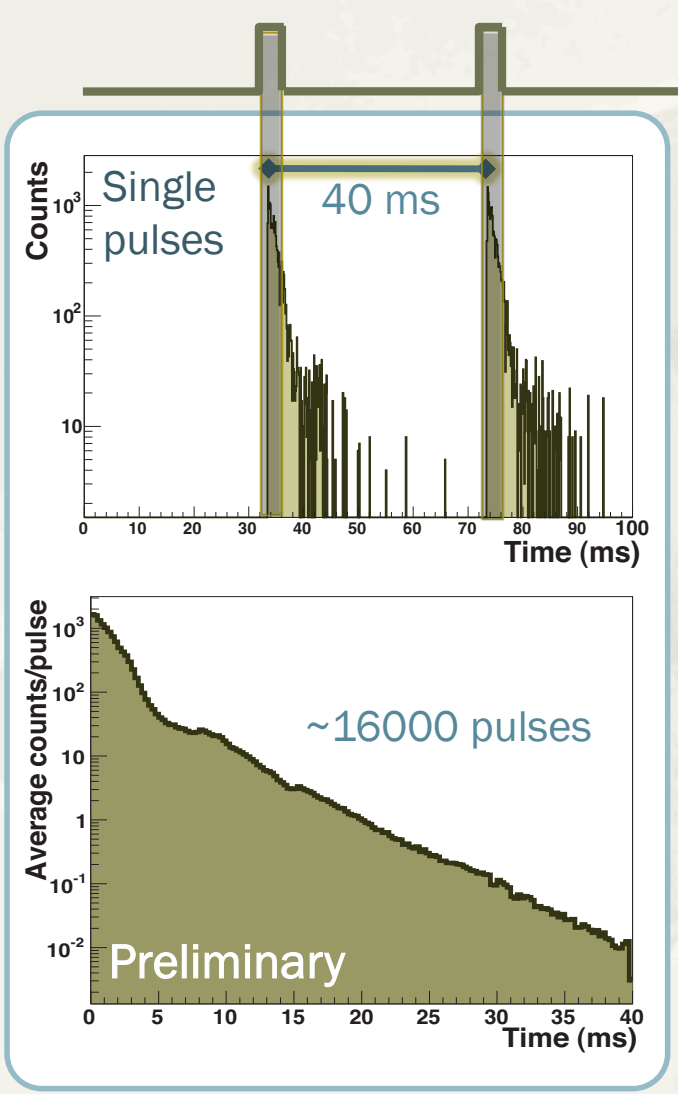
NOBORU beam line



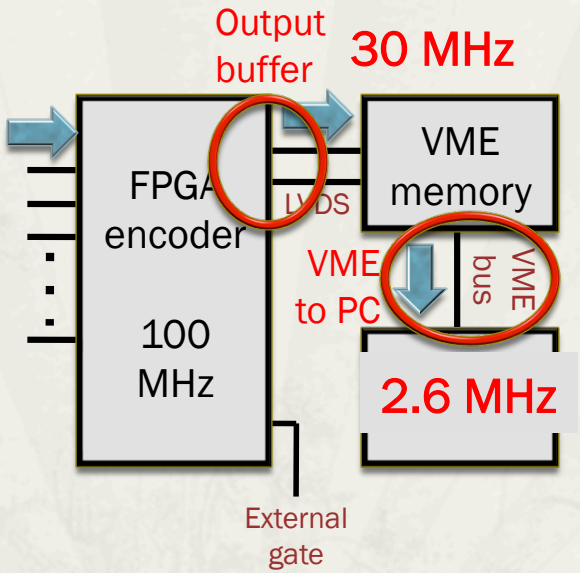
Beam line

- De-coupled liquid hydrogen moderator at 20 K.
- Max. beam size: 10×10 cm^2.
- Moderator-to-detector distance: 14.45 m.
- Pulse rate of 25 Hz and neutron band-width of 10 Å.

Neutron pulses and DAQ rate



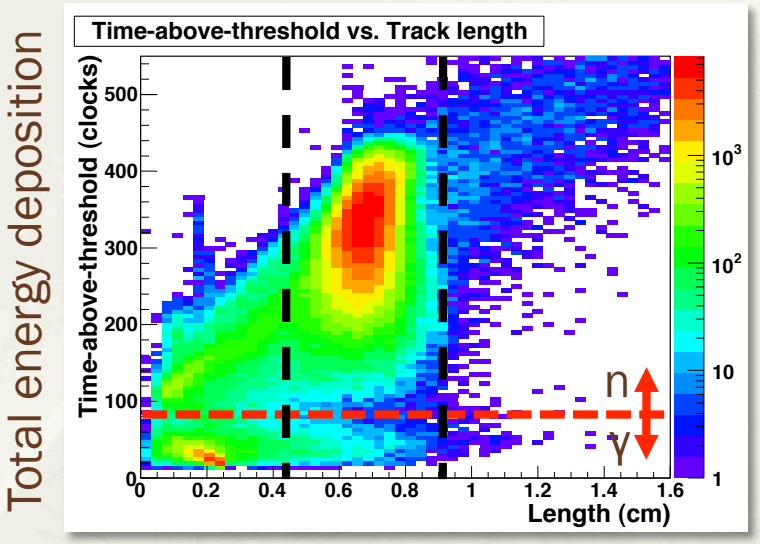
DAQ bottlenecks

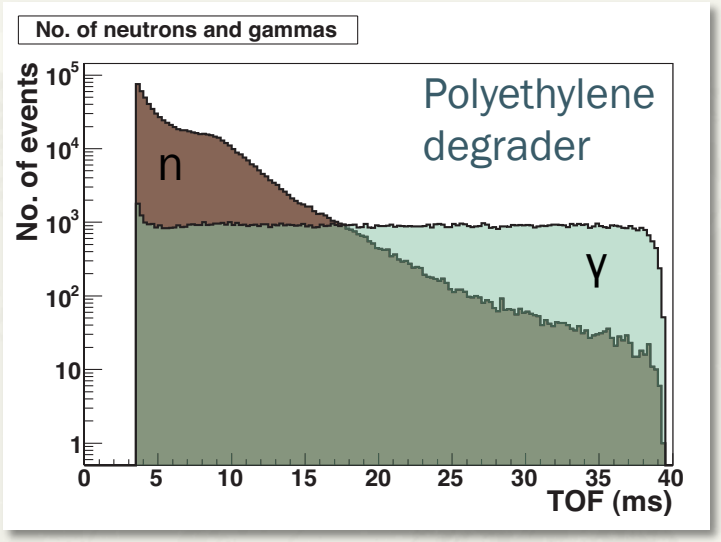


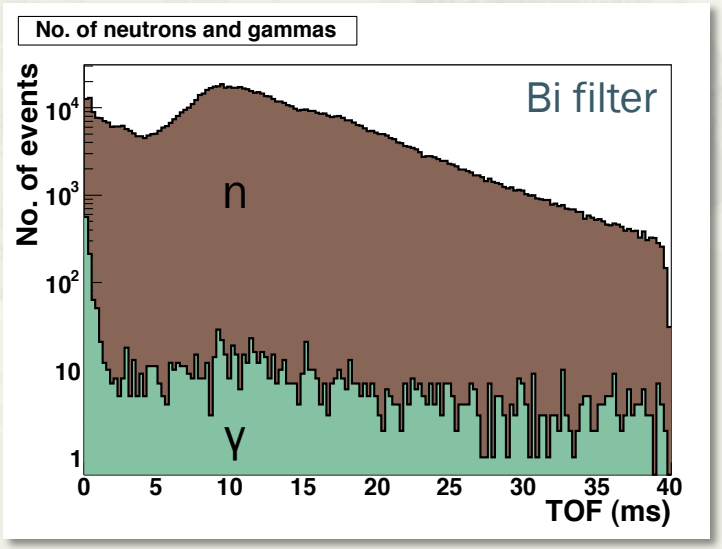
- Encoder output buffer (limits DAQ rate).
- VME-to-PC data transfer (limits DAQ live time).

* Data rates from 100 kHz ~ 4.5 MHz.
* Live time from 15 ~ 60%.
* External TOF gate to reduce dead time.

Neutron/Gamma separation

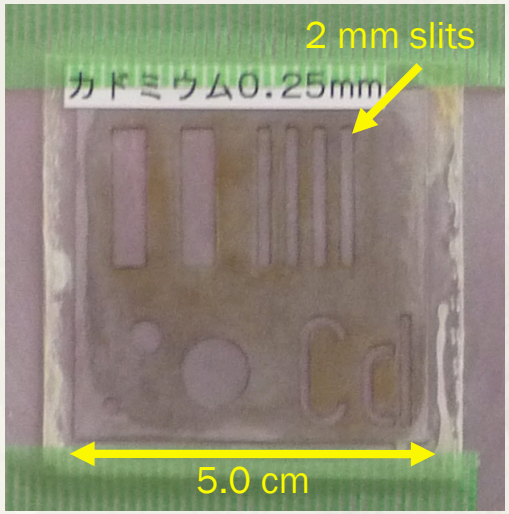






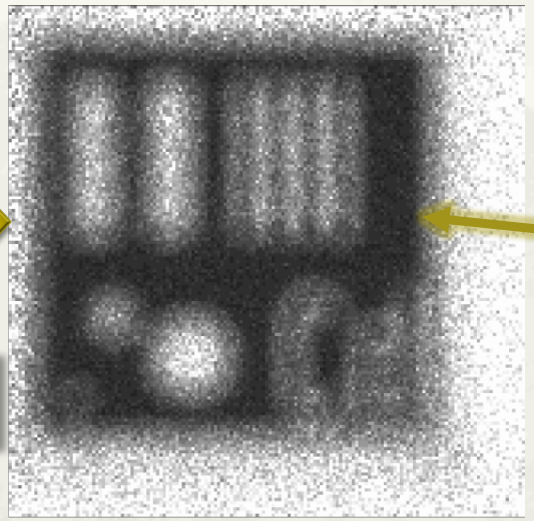
- Cuts in total energy deposition and 3D track length.
- γ/n ratio < 6×10^{-5} with cuts.

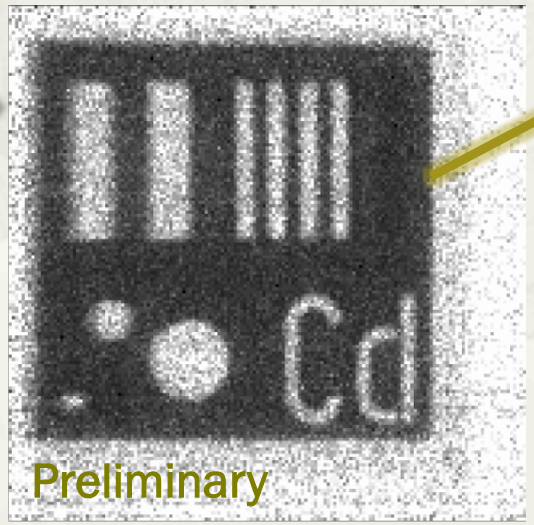
Position resolution with PID



No proton ID

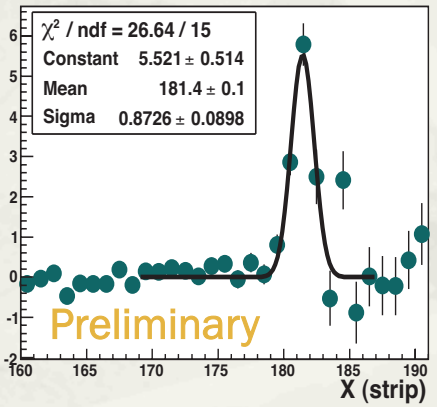
add proton ID





Position from mid-point of p-t track.

Resolution:
960 ± 105 μm (σ)



Resolution from edge:
349 ± 36 μm (σ)

(Includes beam divergence)

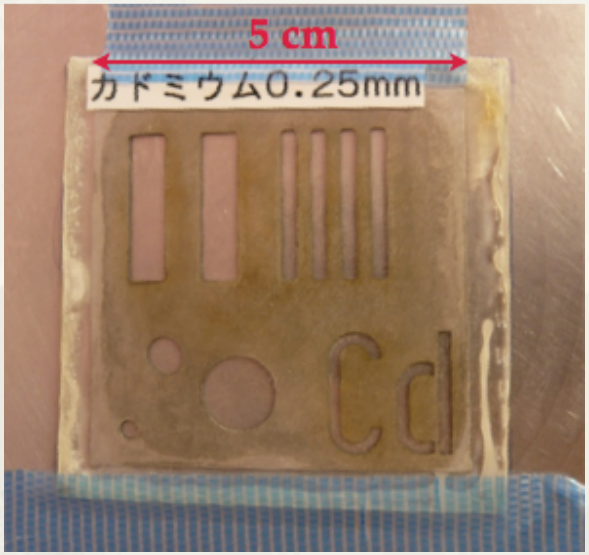
Beam setup

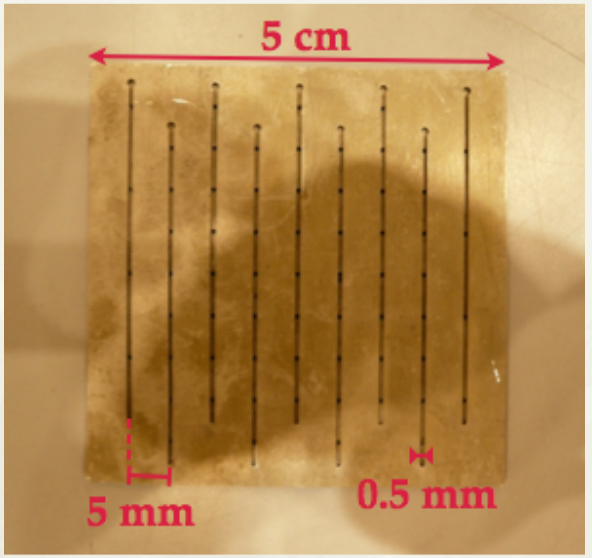
- Slits 1,2: 6 × 6 cm^2.
- 1-cm Polyethylene degrader.

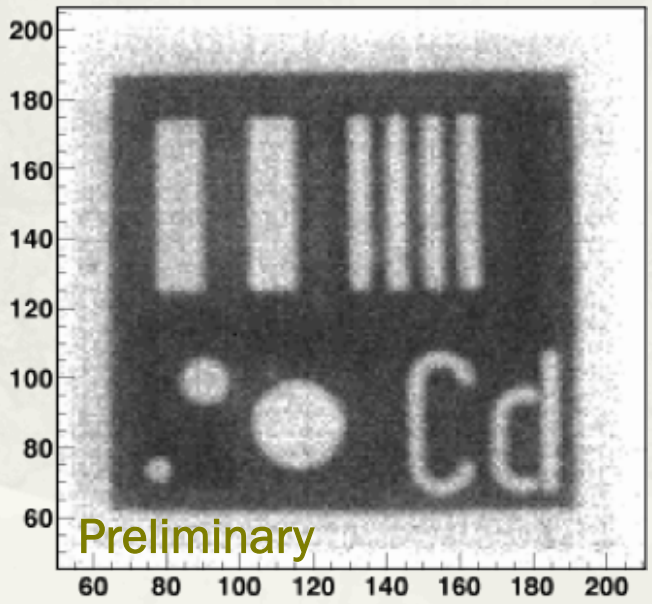
Position resolution

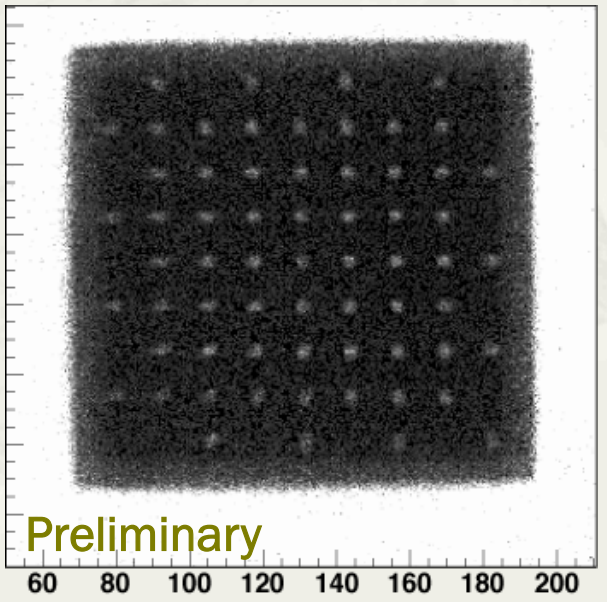
Beam setup

* Slit 1: 0.3×0.3 cm^2.
* Slit 2: 6×6 cm^2.
* Rotary collimator (1×1 cm^2).
* Two 2.54-cm Bi monocrystal filters.

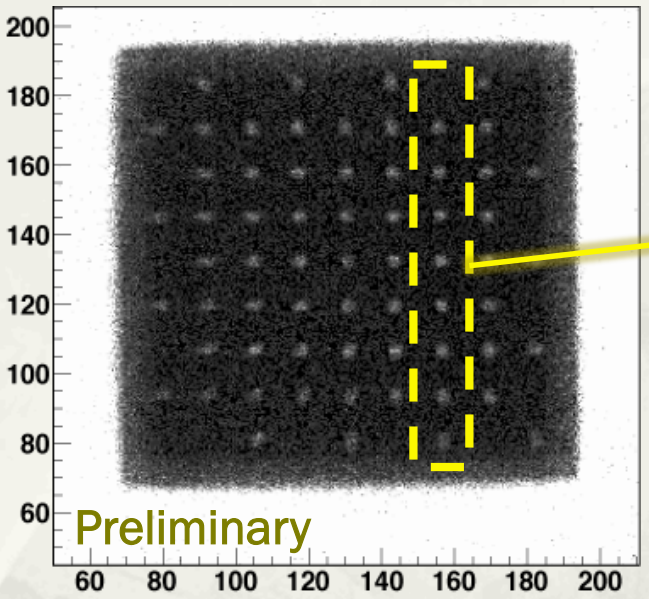


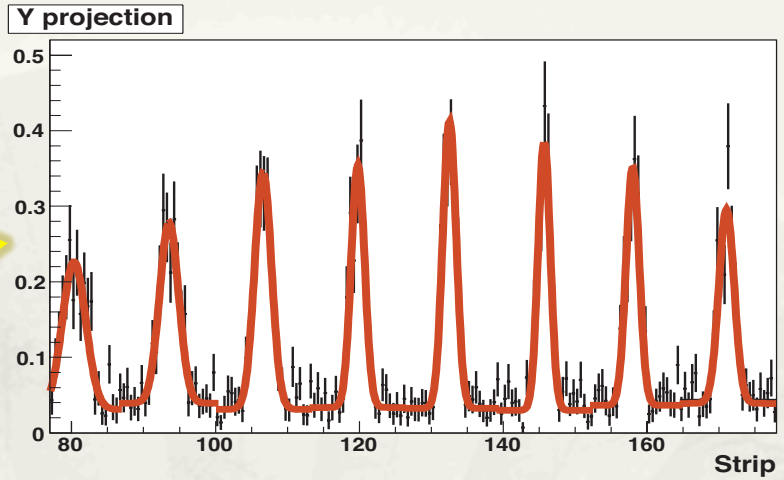


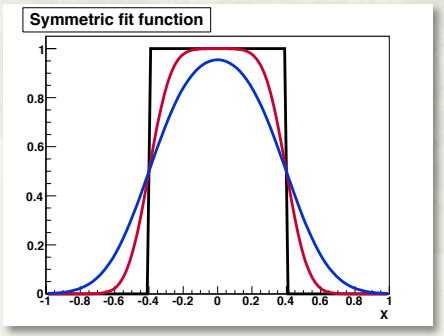




Position resolution from grid



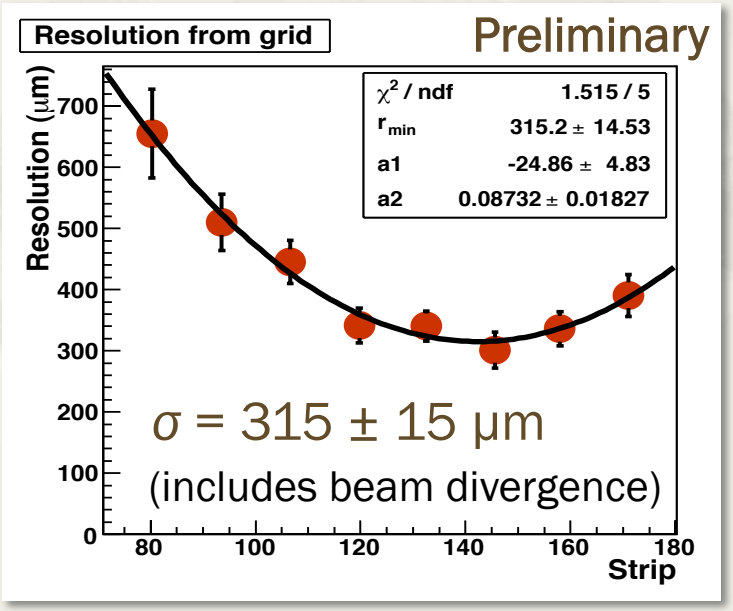




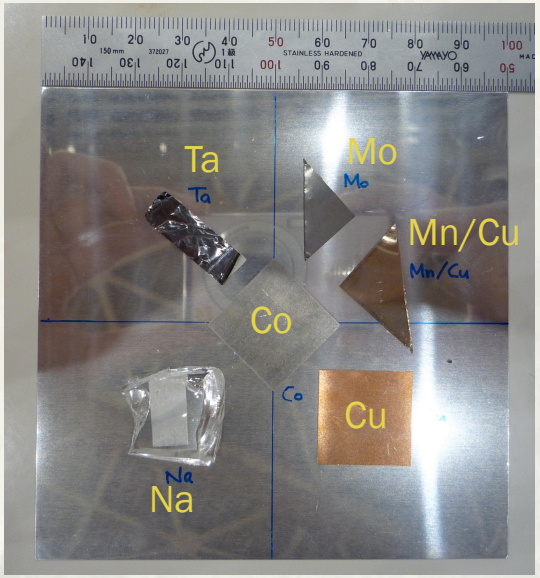
Fit function

Gaussian resolution convoluted with step function.

$$I_{sym}(x) = \frac{1}{2}\left[\mathrm{erf}\left(\frac{a-\mu+x)}{\sigma\sqrt{2}}\right) + \mathrm{erf}\left(\frac{a+\mu-x)}{\sigma\sqrt{2}}\right)\right]$$



Resonance imaging

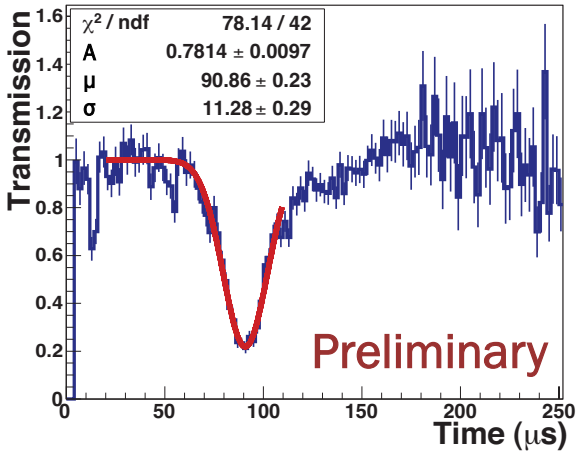


Assorted metals

DAQ rate: 1.48 MHz

Exposure time: 5.5 min

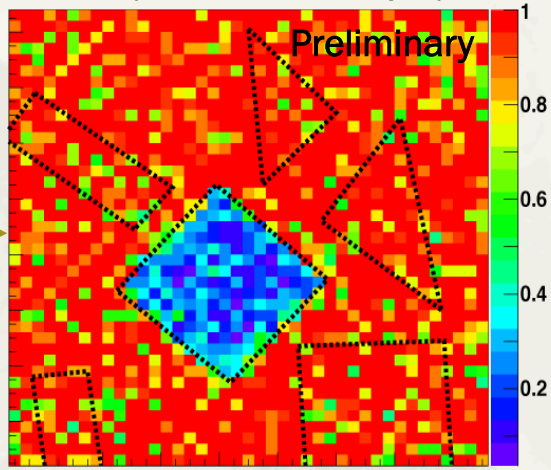
Transmission for ^{59}Co



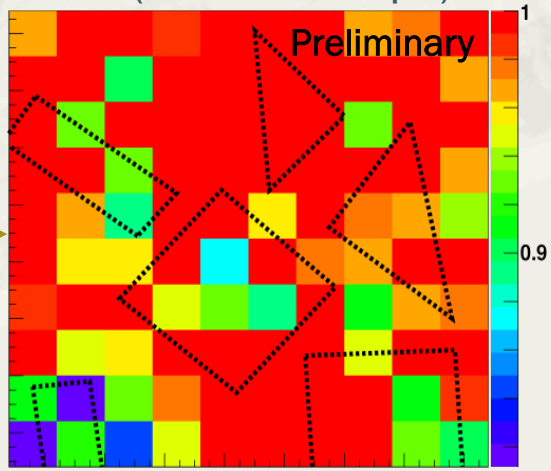
* Known resonance at 132 eV (TOF = 90.9 μs).
* Observed at 90.86 ± 0.23 μs.

Neutrons at resonance energy for selective imaging.

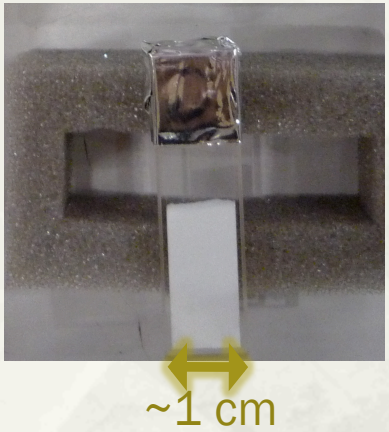
^{59}Co (TOF = 90.9 μs)



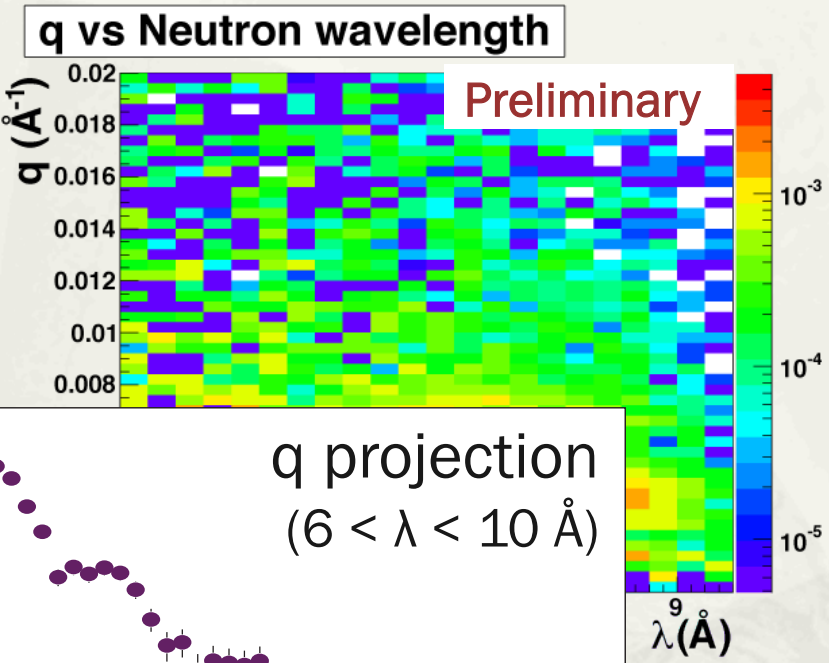
^{23}Na (TOF = 19.6 μs)

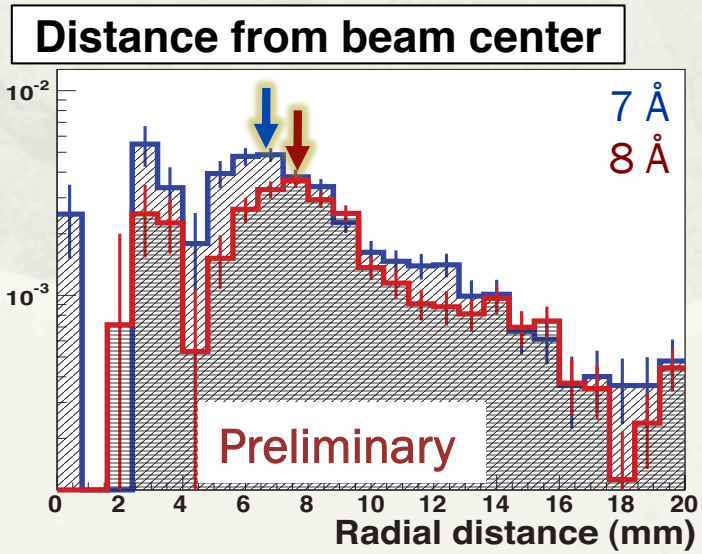


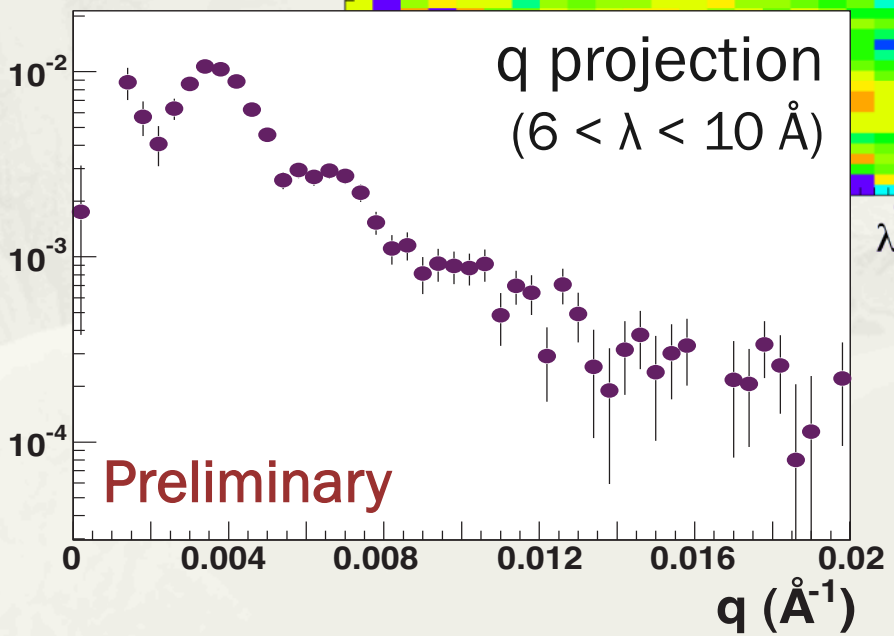
Small-angle neutron scattering



Spherical SiO_2 nanoparticles
Diameter: ~200 nm.
Sample distance: 1666 mm.
Beam size: 4 × 4 mm^2.
DAQ rate: 520 kHz.
Exposure time: 35.0 min.

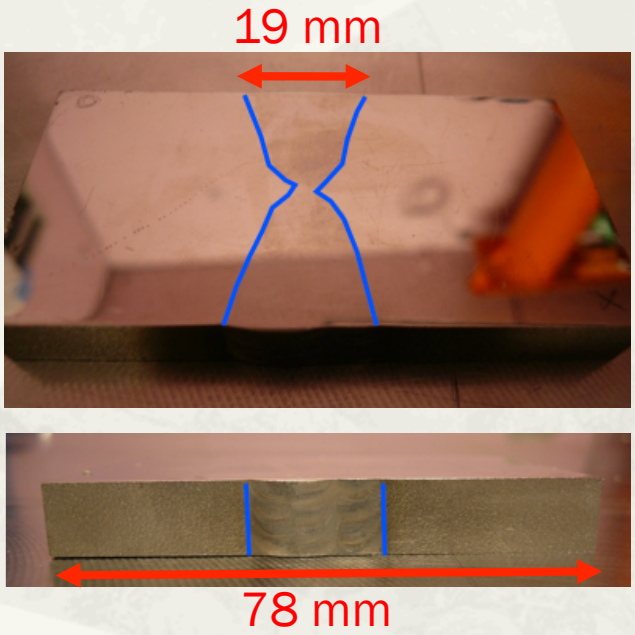


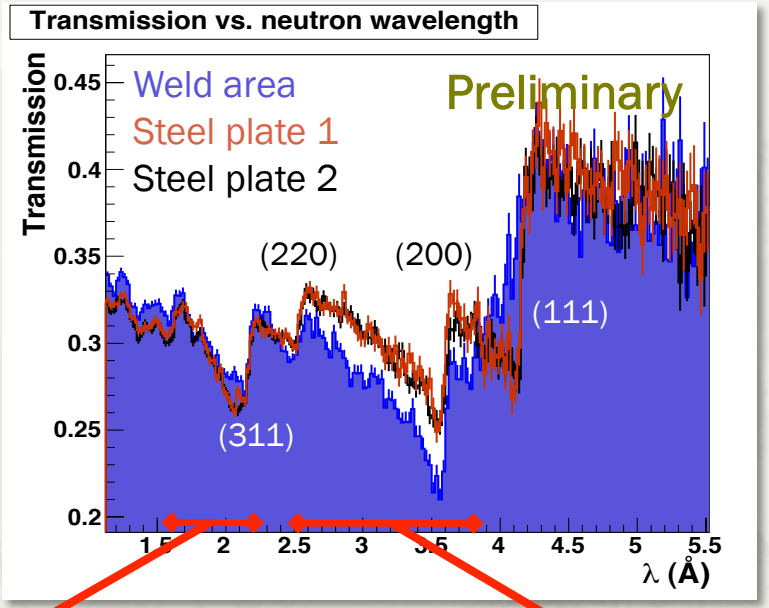


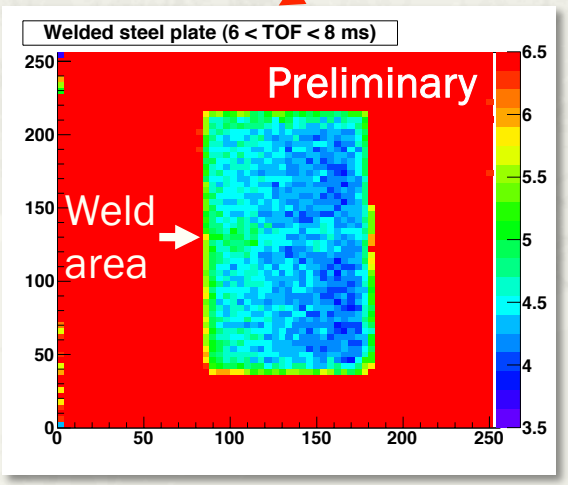


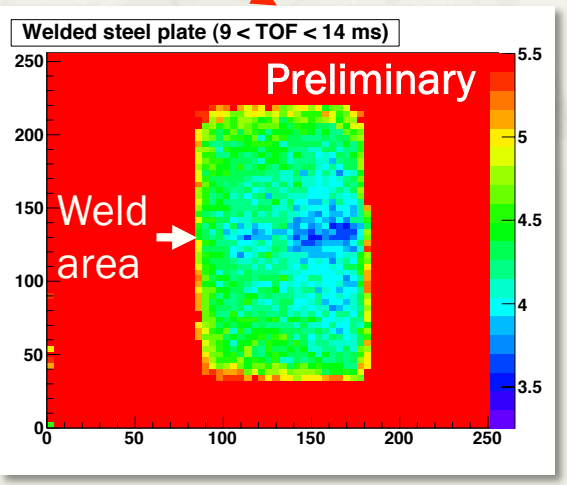
Bragg edge transmission

78 × 40.5 × 10 mm^3 TIG welded 316L stainless steel plate

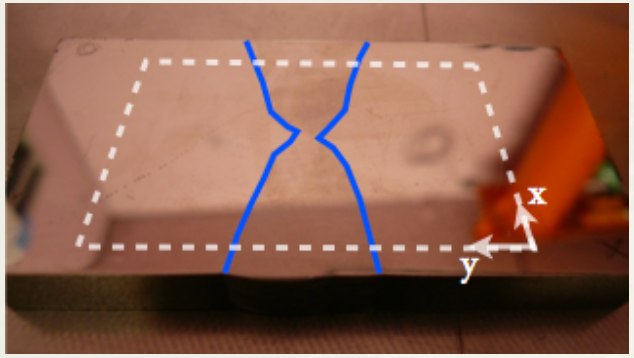




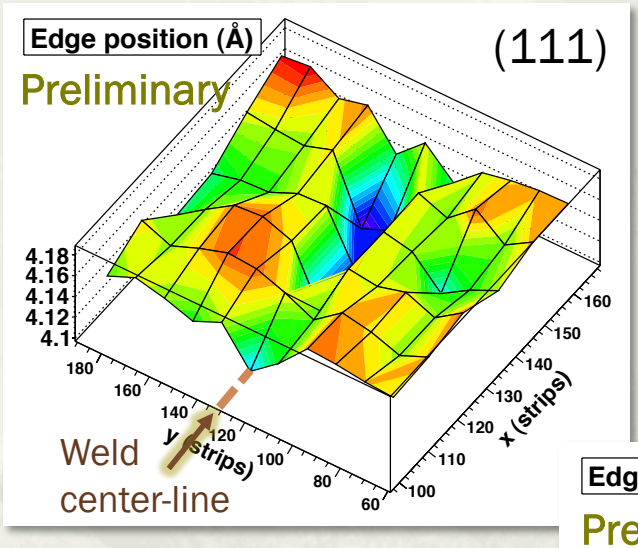


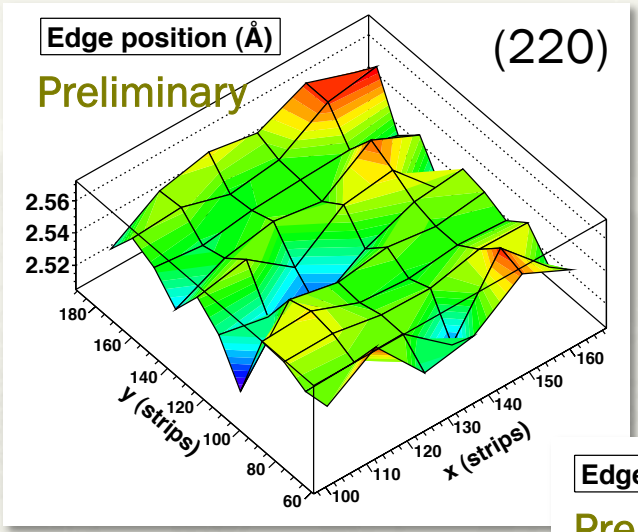


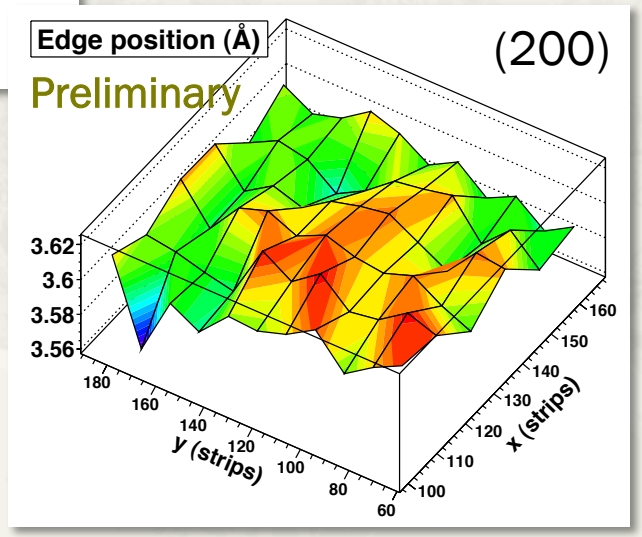
* Edge spacing consistent with FCC crystal structure.

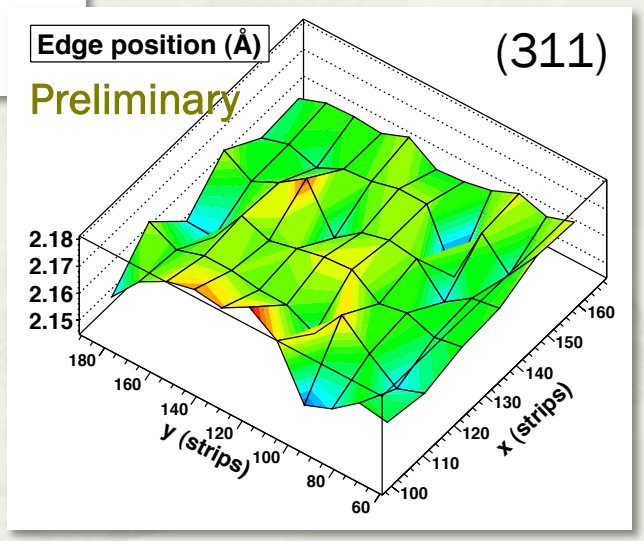


Edge positions using fit function from Santisteban, et al.



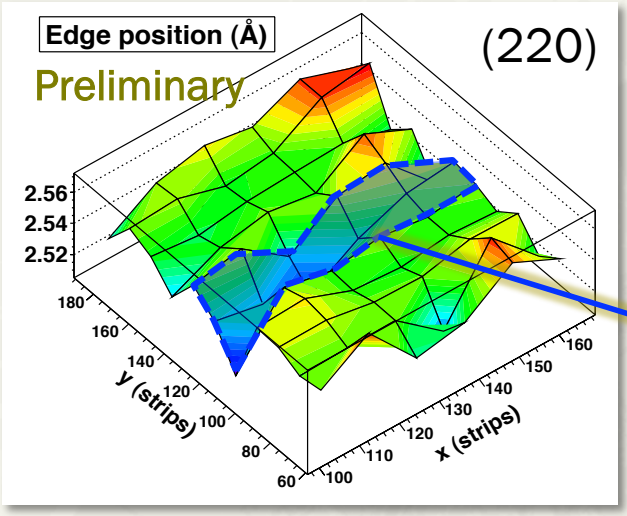


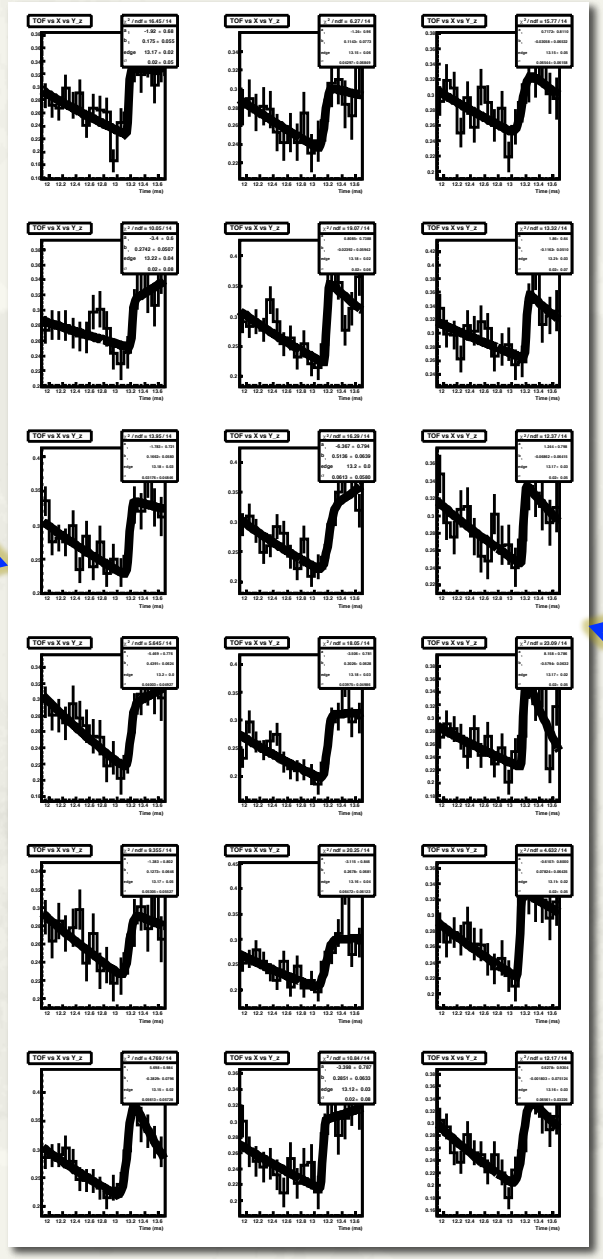


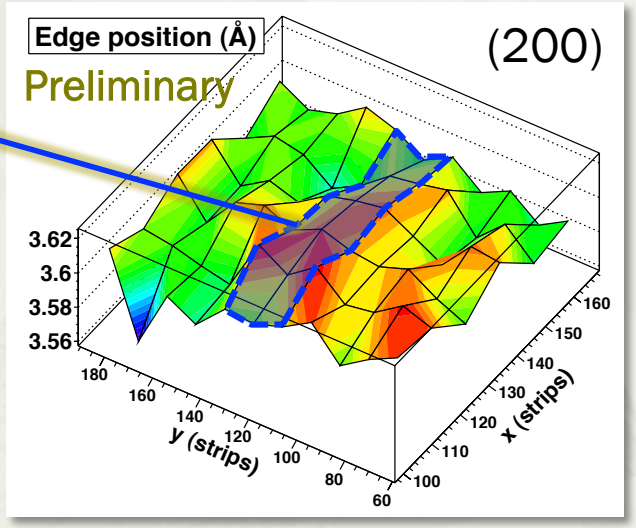


'Pixel' size of 4.8 × 4.8 mm^2.

Transmission spectra







Pixels in the weld region.

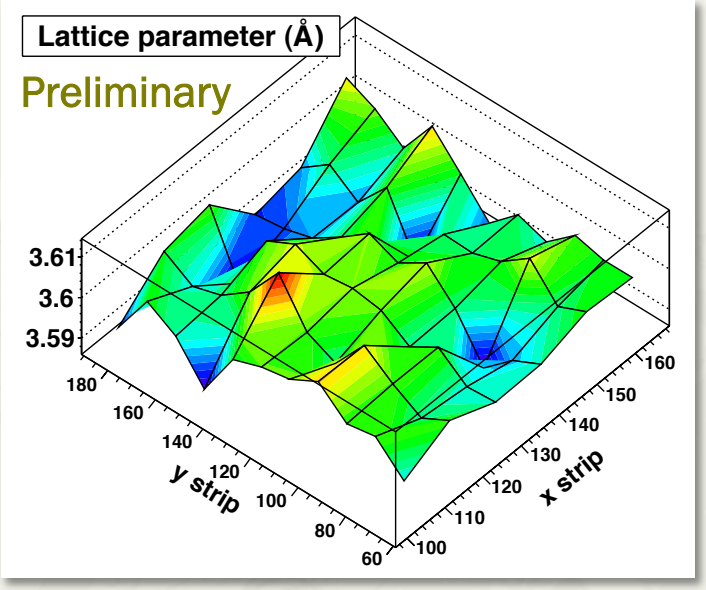
Lattice parameter

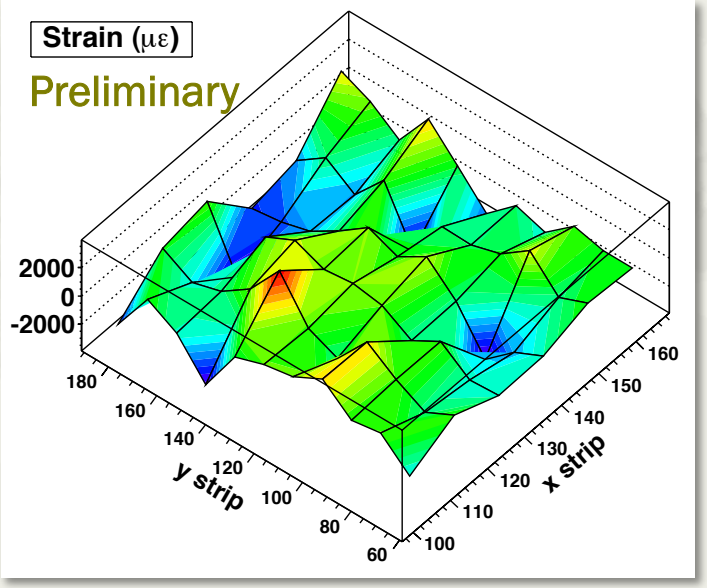
* For cubic crystal:

$$a = d_{hkl}\sqrt{h^2 + k^2 + l^2}$$

* Component of strain in beam direction:

$$\varepsilon = \frac{a - a_0}{a_0}$$





Summary

- TPC based on micro-pattern gaseous detector and FPGA DAQ system.
  - Position resolution of ~0.3 mm; time resolution of ~1 μs.
  - DAQ with high data rates, external TOF gate.
  - Strong rejection of background gammas and fast neutrons.
- Third detector test at J-PARC in 2011.
  - Position resolution with shorter drift cage.
  - Bragg edge transmission with simpler sample.
- μPIC system is available in 10×10 cm^2, 20×20 cm^2, and 30×30 cm^2.
  - Second 10-cm system built for JAEA.
  - Now setting up 20-cm neutron imaging detector for use at Kyoto University.
  - 40×40 cm^2 system and more compact ASD chips are now under development.
  - Manufacturing technique allows wide choice in size and shape.